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ICE-RETREAT IN GLACIAL LAKE NEPONSET AND IN SOUTHEASTERN MASSACHUSETTS.

INTRODUCTION.

LAKE NEPONSET is the name applied to the body of water which, during the final retreat of the Wisconsin ice-sheet, occupied the upper portions of the valley of the present Neponset River a few miles south of Boston. The existence of this lake was first pointed out by Professor W. O. Crosby, who regarded it as one of a series of more or less open lakes, the waters of which had gathered between the general ice-margin and the higher lands bordering the northward-sloping valleys in the region to the southwest, south and southeast of Boston during the period of retreat. The more important of the water bodies beginning at the west are designated by Professor Crosby as Lakes Sudbury, Charles, Neponset, and Bouvé. The deposits and history of Lake Bouvé have been discussed in detail by Dr. A. W. Grabau, while the Sudbury, Charles, and Neponset lakes have been defined and discussed in a more general way by Professor Crosby and Mr. F. G. Clapp.

In the writings of Crosby, Grabau, and Clapp,[1] the view, though not definitely stated, seems to have been tacitly accepted that, although there were doubtless many minor irregularities of the ice-front, the margin as a whole preserved a rather definite and regular terminal facing, such as characterizes living glaciers. It was apparently conceived by the writers named that, as the face drew back to the north, a line of glacial lakelets came into existence at the heads of the northward-leading valleys. These, as the ice retreated, were considered to have grown in size and to have coalesced until the Sudbury, Charles, and Neponset lakes, and possibly also Lake Bouvé, became united into a single lake many miles in width and length, and of considerable area.

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[1] For MR. CLAPP'S present views see paper on "Relations of Gravel Deposits in the Northern Part of Glacial Lake Charles, Massachusetts," pp. 198–215 of the present number of the JOURNAL OF GEOLOGY.

The studies of the present writer in Lake Neponset have led to the conclusion that the ice in that region, instead of retreating with a definite and somewhat regular front, had become absolutely stagnant before the history of the lake began, and that its disappearance was characterized by marked irregularities along lobes, deep re-entrants and detached blocks being the rule rather than the exception. Moreover, the marginal distribution of the deposits makes it seem probable, if not certain, that there was no general body of water such as was postulated for the Sudbury-Charles-Neponset stage, or even for the simple Neponset stage itself, but that the deposits, generally considered as marking the lake level or levels, were laid down in a series of small and more or less independent lakelets existing along the margins of the residual valley lobes or about entirely detached masses of ice.

In urging the improbability of the existence of large lakes with definite levels in this region during the earlier stages, however, the writer does not wish to be considered as denying the existence of considerable bodies of water in the lower portions of the valleys during the closing stages of the lakes when the ice-lobes and blocks had practically disappeared. In the following discussion of Lake Neponset the terms "lake" and "bay" are used to designate those portions of the basin of the Neponset River and its tributaries in which glacial sediments were laid down in standing water irrespective of time, elevation, or of the character of the water bodies in which the deposition took place.

Stoughton Bay is simply a portion of the Neponset basin, lying in the vicinity of the town of the same name. In this bay the conditions which the writer believes to have characterized the ice-retreat in the region under discussion are recorded very definitely in the distribution and topographic expression of the deposits; and, as the history of the retreat in this locality is believed to be essentially the same as in the other glacial lakes of the region; the bay has, for the purpose of discussion, been selected as a type.

STOUGHTON BAY AREA AND ITS DEPOSITS.

Topography and drainage.—In a broad way it may be said that Stoughton Bay occupied a somewhat oval area surrounded by an interrupted belt of hills which, starting northwest of North Stoughton, extends southward about four miles, and then curves first to the west and then to the northwest, finally terminating in the range of hills southwest of Canton. The breadth of this basin is about four miles, and the length a trifle greater. The crests of the hills constituting the boundary vary from 200 up to 420 feet in altitude, while the intermediate cols vary from 190 to 250 feet in elevation.

Notwithstanding these relatively low gaps in the southern rim of the basin, it seems probable that the preglacial drainage, like that of the present period, was by way of the Neponset River to the north. Both the lower level of the rock-floors of the channels and the greater width of the valleys at the northern end of the area bear out this supposition. The possibility of a deflection of the drainage to the southwest through the valley now occupied by Massapoag Pond, has been considered, but although the valley is relatively broad, the frequent projection of rock "islands" through the outwash drift deposits, with which it is filled, appears to indicate that the rock bottom is much higher than in the present valley at Canton Village. The Canton valley, however, is not a broad one, the rock outcropping at relatively short distances from the stream on both sides, and probably underlying it at no great depth. The high elevation of the bottom of this channel, as compared with the low elevation, which probably characterizes the near-by Neponset valley bottom, would appear to indicate, either that the former is not the main preglacial drainage channel, or that the Neponset valley has been materially deepened by glacial erosion. The latter appears to be the more probable. In fact, the drainage and topography of even the bed-rock areas of this portion of Massachusetts show very few of the characteristics of normally developed drainage systems.

Relatively little is known as to the minor details of the rock topography within the basin, as the floor is deeply covered, except perhaps in the center, with extensive planes of stratified drift, which rises in places to nearly 150 feet above the marshy tracks along the main streams, which in turn are of unknown, though probably not very great, elevation above the rock-floors beneath them. The wells in the region are generally shallow, and in most instances afford little information of value. The details of the plains and of the cols in the rock-rim, many of which served as channels for the overflowing waters, can be considered to the best advantage in the discussion of the various stages in the history of the bed.

STAGES OF DEPOSITION.

The history of the Stoughton Bay area of Lake Neponset may be said to have begun when the first body of water came into existence between the ice and the retaining walls of the basin. Such a lakelet must of necessity have been of small size at the beginning, but soon became enlarged through the melting back of the ice. The outlets may have been over low points in the rock-rim, or along the edges of the ice. As the melting progressed, the expansion of the lakelets continued until the lower outlets of the waters were uncovered.

The different levels of the waters are indicated approximately by the altitude of the stratified deposits, which were laid down during the different stages. In Stoughton Bay these deposits are of two general levels, the higher standing at 250 feet, and the lower at about 190 or 200 feet above the level of the sea. The higher stage is named from the town of Stoughton, the greater part of which is located on the high-level deposits, while the lower stage is named from the village of Springdale, near which the lower planes are strongly developed.

The distribution of the materials show that not all the deposits, even of a single stage, were laid down in the same body of water, but accumulated, on the contrary, in more or less separate lakelets. The principal water bodies of the higher stage were the Rattlesnake Hill, East Sharon, and Stoughton lakelets, while the leading bodies of the lower stage were the Elm and Springdale lakelets.

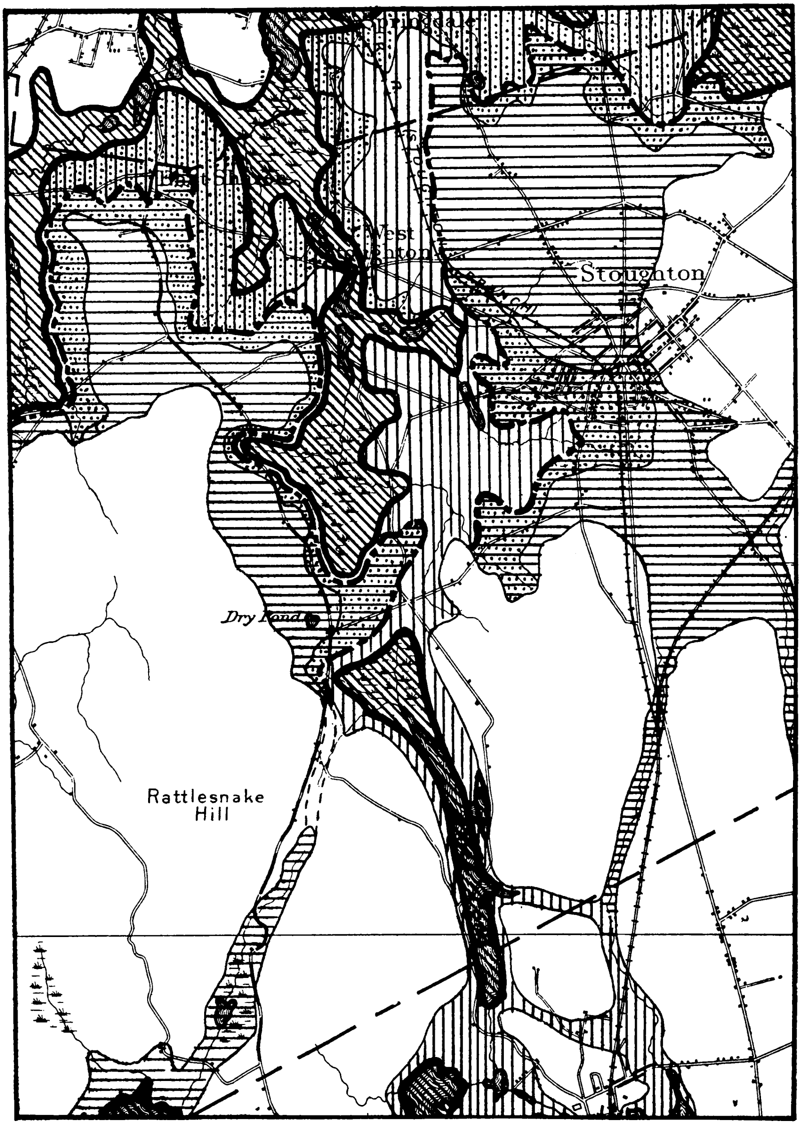

FIG. 1.—Retreatal Stages in Stoughton Bay of Glacial Lake Neponset.

□ Rock and till, generally higher than "high-level" plains.

▤ High-level plains and outwash of East Sharon and Stoughton lakelets.

▤ Gradation deposits between high- and low-level plains.

▥ Low-level plains and outwash of Elm Street and West Stoughton lakelets

▥ Gradation deposits below low-level plains.

▧ Ice-masses at close of low-level stage of lakelets.

Position of ice-margin at opening of high-level stage.

Position of ice-margin at close of high-level stage.

Position of ice-margin at close of low-level stage.

EARLIER OR STOUGHTON STAGES.

Rattlesnake Hill lakelet.—This is the smallest of the recognized lakelets of the Stoughton Bay area, being less than half a mile in length and only about one-eighth of a mile in width. It was formed in a re-entrant just north of the col between Rattlesnake Hill, rising to 420 feet on the northwest, and another granitic hill, about 360 feet in height, on the southeast. The rock-floor of the col is not now exposed, but as there was free drainage to the south, the deposits though constituting a somewhat broad and flat sheet, are probably of slight thickness at the crest. The surface of these deposits stands at 250 A. T.

The deposits of the locality may be divided into three classes: (1) the outwash deposits in the channel leading southward from the col; (2) the flat top deposits at and just north of the crest; and (3) the irregular and broken delta deposits on the north (Fig. 2).

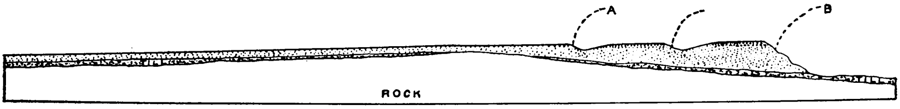

FIG. 2.—Diagrammatic north-south section through Rattlesnake Hill divide, showing outlet and broken delta deposits. (*A*, *B*, etc., show successive stages of ice-front during its recession.)

The outwash gravels, which constitute a gentle sloping deposit extending down the valley to the southward, were evidently formed not later than the period when the ice-margin rested at the point represented by *A*, as the unfilled kettles and other depressions between the imperfect deltas to the north indicate that in the later stages little or no material was being carried into the lakelet.

The deposits at and just north of the crest consist of sands and fine gravels, and evidently represent the perfected lake deposits. They present an almost perfectly flat surface, one-eighth of a mile in width, and perhaps twice as long, which is so ill drained that in the wetter seasons the water stands over several acres, though of a depth of only a few inches. It is now the site of a cranberry bog. From this flat the rock hills rise with a sharp line of demarkation abruptly on each side.

At the time the deposits were laid down the ice probably presented a fairly definite face to the lake, the position being not far from the crest of the pass possibly near *A*. Later, however, the margin became broken up into detached blocks at its edge, the location of these blocks being represented by the imperfect planes and kettles lying just north of the crest. Continuing to the north, the deposits of stratified material end rather abruptly, the lower portions of the northward-leading valley, through which the ice drew back, being practically free from them. This would seem to indicate, either that the glacial streams had been diverted at some point farther north, or that they no longer carried any material quantities of sediments. Otherwise the deposits would have continued to accumulate in the lakelet which, in the later stages, must have reached some distance to the north of the deposits previously noted. The waters passing out from the lake to the south, being no longer overloaded with materials carried in suspension, began the work of eroding out the deposits laid down in the earlier stages, with the result that a thickness of ten feet of sand and gravel was removed throughout nearly the entire width of the valley leading south from the pass, the original level being represented only by an occasional terrace remnant standing about ten feet above the present valley floor. Imbedded in the silt, which here constitutes the floor, is a granitic bowlder, nearly fifteen feet in diameter, probably stranded on the rock or till surface underlying the silts during the melting of the ice and surrounded by subsequent deposits of sand.

East Sharon lakelet.—This name is applied to the body of water which lay between the granitic hills, one and one-half miles south of East Sharon, and the ice-front after the latter had shrunk back from the valley sides. The lakelet had a total length of approximately two and one-half miles. The greatest extent of open water was south of East Sharon (southwest of West Stoughton), where the lake measured a mile or more across. A mile southwest of West Stoughton the lake became contracted into what must have been simply a rather broad and sluggish lateral stream, which, however, opened up again to the southward into a marginal body, one-quarter of a mile or more in width, which continued to the north base of Rattlesnake Hill.

In this compound lakelet the deposits of the East Sharon stage were laid down by the superglacial streams from the surrounding ice. The sand and gravel plains are most perfectly developed along the hillsides, as the lakelet was there shallowest and soonest free from ice. In such situations the plains were frequently built up to a horizontal upper surface, coinciding approximately with the water level, and are generally free from kettles. As the ice receded, lower portions of the hillsides were uncovered, and the water became deeper. The ice, however, melted back most rapidly along the surface of the lakelet, leaving projecting edges beneath the water, which became covered with sands and gravels. On the further melting of the ice and its disappearance from beneath these gravels, the materials were let down into irregular accumulations along the sloping valley sides, constituting the gradational deposits between the upper and lower plains, and between the lower plains and the present valley floor in the Stoughton Bay area. When the ice-wedge was very thin, gentle and fairly regular slopes resulted when the materials were let down, but when thicker, steeper and kettle-pitted slopes resulted. Dry Pond, in the southern part of East Sharon, is an example of such a kettle. This is the explanation of the change from a flat to a gently sloping plain, and finally to the irregular hummocky slopes which characterize the plains at many points in this area. The steeper ice-contact slopes, which are especially well developed in portions of the east side of the East Sharon plain, were formed where the marginal ice-wedge was only slightly developed. That the slopes of the plains cannot be regarded as purely depositional is shown by the fact that the inclination of the surface is opposite that exhibited by delta plains.

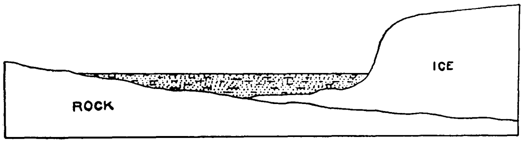

FIG. 3.

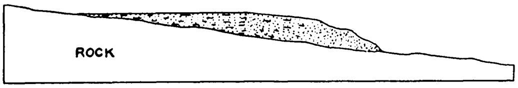

FIG. 4.

FIGS. 3 AND 4.—Showing mode of formation of gradational deposits: 3, marginal deposits before recession of ice; 4, plain and gradation deposits after recession of ice.

There can be no question that the materials of the plains came from the ice. This is attested by the rounding of the pebbles, the lack of agreement in composition between the gravels and the adjacent rocks or tills from which they must otherwise have been derived, and the absence of even the most local postglacial deposits of similar character in the region.

The lake-level was regulated by the altitude of its outlet, which was through the notch southeast of Rattlesnake Hill, as in the case of the eariler lakelet of that name. The outlet stream was marginal as far south as the northeast base of the hill, but there the waters passed onto the ice, on which they continued until the notch was reached, as shown by the absence of erosional or depositional features in the intervening area.

That there was no outlet over the divide south of Massapoag Pond, which lies some two miles west of Rattlesnake Hill, is shown by the fact that the rock-floor is from ten to twenty feet or more lower than at the Rattlesnake Hill outlet, and as much below the level of the East Sharon and Stoughton Plains, the highest of which it could not, therefore, have controlled. The field evidence, moreover shows that the Massapoag valley was occupied by ice until a late stage in the history of the Stoughton Bay region.

Stoughton lakelet.—This is by far the largest of the lakelets in the Stoughton Bay region, and receives its name from the town of Stoughton which is located in the middle of its area. Like the East Sharon lakelet, it was compound, being composed of a larger water body at the north and a smaller one at the south, the two being apparently connected by a narrow channel along the eastern margin in the vicinity of Stoughton. Like the East Sharon lake, it was also located, at least so far as the northern or main portion is concerned, at the termination of a rock hill projecting between two converging valleys in which the ice still remained.

The breadth of the northern portion of the lake from north to south was about one and one-half miles, and from east to west about one and one-quarter miles. The southern portion of the lake was more irregular. From east to west it measured somewhat over a mile in length, but it was less than half a mile in width.

In the northern half of the lakelet the broad Stoughton plains were deposited. While in a general way these plains present a uniform upper limit, the plain was in many places never built up to a perfectly smooth surface, but is characterized by broad, gentle undulations, merging into kettles about the margins. Some parts, however, are as flat as a floor. In the southern half of the lakelet the plains are generally quite broken, though occasional flat-topped areas exist. The margins of the plains nearest the valleys present in both areas the same gradational type as the East Sharon plains.

The natural outlet of the Stoughton lakelet would at first sight appear to have been southward along the valley followed by the railroad, or along the similar valley half a mile farther east. The altitude of these outlets in each instance, however, is less than 200 feet, while the flat tops of the sand plains, which probably indicate the approximate level of the water of the lake, is 250 feet, or the same as that of the Rattlesnake Hill and East Sharon deposits. It seems clear, therefore, that the southward valleys mentioned were still blocked by the ice. The elevations of the Stoughton plains, corresponding as they do with that of the Rattlesnake Hill outlet, suggest that it was through this notch that the water passed on to the south. To do this it must have crossed the tongue of ice still occupying the valley north of Ames Pond. An examination of the locality seems to show beyond reasonable doubt that this was in fact the case, the waters crossing just north of the road leading eastward from near Dry Pond. The waters in passing deposited much material on the ice, which, on the melting of the latter, was left as an irregular belt of sands, gravels, etc., across the valley at the point indicated, and practically connecting the Stoughton with the East Sharon plains.

LATER OR SPRINGDALE STAGES.

Elm Street lakelet.—This lakelet came into existence after the ice-margin had melted back to a point a mile or more to the west of the position it occupied during the deposition of the Stoughton plains. The lakelet proper was about three-quarters of a mile wide from north to south, and a mile from east to west. In it was deposited the typical flat-topped plains traversed by Elm and Water Streets about a mile southwest of Stoughton. Its upper surface stands at an elevation of 210 feet, and the plain is bounded on the northeast, north, and west by sharp ice-contact slopes, while on the east and south it slopes off into rolling deposits, apparently quite distinct from ordinary fore-set slopes, and probably representing deposits along the subaqueous ice-wedge, afterward let down as irregular gradational masses, as explained in the case of the East Sharon plains.

The altitudes of the upper limit of the flat-top deposits indicates that the Rattlesnake Hill outlet had been abandoned, and that a newer and lower outlet to the south had been opened up through the valley occupied by Ames Pond at a level of about 210 feet. The ice had not entirely left the valley, a narrow tongue still remaining in the center, along both sides of which, as indicated by terraces with ice-contact slopes toward the valley, outflows took place. On the west side the water followed straight through the valley, but on the east side a portion passed off to the eastward by sub-outlets through notches located respectively near where the highway crosses the pond and just above the south end of the pond.

West Stoughton lakelet.—The West Stoughton lakelet was a body of water one and one-half miles long and one-half a mile wide, extending from Springdale on the north to a point about a mile west of Stoughton on the south. The plain which now marks its position, though fairly flat in places, is much more broken than most of the other plains described, presenting in many places rolling and kettle topography characteristic of deposition open and around more or less detached sheets or blocks of ice. Fine ice-contact slopes extend all the way around the edge from West Stoughton to Springdale, marking the margin of the ice, still occupying the center of the valley.

The elevation of the surface of the West Stoughton plains is from 190 to 200 feet. It seems to have been formed at a slightly later period than the Elm Street plain. The lower altitude of its surface is probably due to the fact that the ice in the depression now occupied by Ames Pond (artificial) had finally disappeared, opening up an outlet a few feet lower than that existing at the time the Elm Street plain was formed. The surplus waters probably escaped through the main and two sub-outlets in the vicinity of Ames Pond as in the case of the Elm Street plain.

Closing stages.—Within the limits of the Stoughton Bay area there are no records of Lake Neponset later than the stage marked by the deposition of the low level plains just described, unless certain unimportant irregular deposits occurring in the center of the valley are regarded as marking the final passing away of the ice. The ice already reduced to a mere line along the center of the valley could have remained but a short time, and, as the later outlets appear to have been to the north, no further stages of the lake are recorded.

RETREATAL CONDITIONS.

Absence of ice-movement.—That ice-movement had ceased before the opening of the lake history of the Stoughton Bay area is clear from the character and distribution of the deposits laid down. Nowhere in the region are there any deposits of the nature of moraines, such as would have been formed at the front of a living ice-sheet. This applies both to the uplands and to the valleys, which are alike free from till accumulations formed either along a general ice-front or at the terminations of valley ice-tongues.

The form and structure of the stratified deposits also fail to show any forward movement of the ice-bodies, along the margins of which they were laid down. Folding and faulting of a nature indicating thrusts are absent in all exposures which have been seen, and the ice-contact slopes are practically free from till accumulations, such as would have been formed if the ice had possessed sufficient motion to bring fresh materials to the front. The topographic forms are always those which would result from a receding ice-margin, never from an advancing one. The gradational deposits described on pp. 185, 186 are especially significant in this connection.

The strongest evidence, however, is from the distribution of the deposits, which, as has been described, form relatively narrow and successive strips along the sides of the valleys, showing conclusively, when examined as a whole, that the ice-shrinkage was not from south to north, or any other fixed direction, but always away from the valley sides. At the latest recorded stage, as shown by the surrounding deposits, only a narrow strip of ice remained along the center (Fig. 1). Neither this nor the earlier and wider masses possessed the straight or gently curving outlines characteristic of living ice-tongues, but were marked by all the sinuosities and irregularities of an irregularly melting stagnant ice-margin.

Drainage of the ice-sheet.—The highest stratified deposits of Stoughton Bay are the Rattlesnake Hill, East Sharon, and Stoughton plains, which were deposited in standing water at an altitude of 250 feet. These plains have an aggregate area of at least five square miles, and a probable average thickness of 75 feet. Certain reasons have already been given (pp. 183, 184) why these deposits cannot be regarded as derived from the surrounding uplands, but the most conclusive argument is their immense bulk, considered in connection with the absence of erosion features on the surrounding uplands. That the material came from the ice, therefore, there can be no doubt. The question then is: Were they deposited by subglacial or by superglacial streams?

Half a mile southeast of East Sharon the plains, which here consist of sands and of gravels with pebbles up to several inches in diameter, stand at an altitude of 245 feet, or over 100 feet above the valleys on the east, north, and west, across which the materials must have been borne. If the gravels were transported by subglacial streams, they must have been suddenly lifted a distance of 100 feet. To move a pebble 2 inches in diameter along a level bottom requires a current with a velocity of 2.8 feet per second; to lift it upward requires a velocity of about 3 feet per second. This would correspond to an upward pressure along the assumed ice-tunnel across the valley to the north of 43 pounds to the square inch, and to indicate a head of 2 feet per mile in a straight conduit like that of a circular pipe 6 feet in diameter. In a conduit with the many irregularities of a glacial tunnel the head would probably have to be 10 per cent. greater, or approximately 3¼ feet per mile, in order to give the observed velocity. Slightly lower figures would be given by larger conduits. Such a head could be found at a distance of many miles to the northwest. In living glaciers subglacial streams may possibly exist for considerable periods of time, but it seems beyond the ground of probability that a subglacial stream, with the pressure indicated, could continue over hill and valley for long distances beneath the stagnant ice-sheet without finding a passage for the more ready escape of its waters.

The temperature of a subglacial stream is always, according to observations, slightly above the freezing-point. The corrosive action of a stream, with the velocity and pressure indicated, would rapidly eat the roof of its tunnel, until during a somewhat extended period, such as would be required for the upbuilding of extensive plains like those of the Stoughton Bay area, a base-level was reached. In crossing a valley the roof of the tunnel would be at least as high as the median height of the valley walls on the up-stream and down-stream sides. The motion of the water would be mainly superficial, and the lower or slack-water portion of the tunnel in the valley or depression would become filled to grade with deposits, which would eventually be left as an immense esker. No deposits of such a character occur in connection with the plains in this region.

In case of the plains of the Stoughton Bay area, there can be no doubt that the streams supplying the material were englacial or superglacial. Of the two, superglacial streams are the more probable. It is clear that there was a connection across the ice between the Stoughton and East Sharon plains, while the waters from both flowed a short distance over the ice in their passage through the Rattlesnake Hill outlet. If superglacial drainage existed at one point, it is likely to have existed at several, and, in the absence of all evidences of subglacial drainage, can reasonably be accepted as the predominant type. It is not assumed that subglacial drainage was not common in other regions, nor that it did not exist to some extent in the region now under discussion; but it played little or no part in the upbuilding of the plains.

Inception of lakelets.—In an earlier paragraph it has been pointed out that there is every reason to believe that the ice had become stagnant before the first of the lakelets of the Stoughton Bay area came into existence, and it is probable that all movement had ceased while the entire surface of the region was still covered by the ice. As the melting of this stagnant ice-field went on, the hilltops began to appear, and the superglacial drainage was obliged to seek the notches for outlets. Seemingly, the first pass to be uncovered was the one immediately west of Rattlesnake Hill, at an altitude of approximately 325 feet; but it appears to have been so situated that it was not available to any of the superglacial streams, for an examination of the ground shows that there was no outflow of water through this pass. Following this, the next to be laid bare as the melting progressed must have been the notch immediately east of Rattlesnake Hill, at an altitude of 250 feet. This is the outlet which is known as the Rattlesnake Hill outlet.

Lakelets of the earlier stages.—The position of the ice-front at the beginning of the flow through the outlet was very near the crest of the pass, as indicated by the distribution of the plains. Later, however, the ice drew back slightly, while farther north it receded at the same time from the valley walls sufficiently to bring into existence the East Sharon lakelet on the west side of the valley and the Stoughton lakelet on the east. Ice-masses still occupied the Massapoag and Ames Pond valleys, and the two southward-leading valleys southeast of Stoughton, leaving the Rattlesnake Hill notch as the only available passage to the south. The outlets of both lakelets were through this pass, to reach which the drainage of both, as has been explained, passed over the ice itself for a short distance.

Opening of the Ames Pond outlet.—The earlier or high-level stages of the Stoughton Bay lakelets were brought to a close when, by the shrinking away of the ice from the retaining hillsides, lower outlets were opened through the valley of Ames Pond. This valley is marked on both sides by terraces exhibiting ice-contact faces on the sides nearest the pond, constituting, in fact, true kame or morainal terraces—a feature not often recognized in eastern Massachusetts. From these it is evident that an ice-tongue still remained in the middle of the valley. This was at first possibly connected with the larger remnant of the ice farther north in the valley, but the melting of the ice, which had previously proceeded slowly by ordinary surface ablation, now probably went on with much greater rapidity, owing to the action of running water on both sides of the valley mass. This rapidly cut away the ice, already greatly reduced by the stream crossing from the Stoughton to the East Sharon lakelet, with the result that the Ames Pond mass was early separated into an independent block.

Lakelets of the later stages.—The Elm Street lakelet was the first of the lower-level bodies to be formed, and the waters found outlet along both sides of the Ames Pond block, forming the kame terrace deposits mentioned. The waters in part passed out from the valley by a bowlder-strewn gorge through granite ledges at the head of the bay just southeast of the highway across the pond, in part by the wider, sand-filled valley between rock hills just above the lower end of the pond, and in part directly southward along the main valley.

Following the Elm Street, the West Stoughton lakelet was formed. By this time the Ames Pond block had become much contracted, or had entirely disappeared, affording an outlet, from 10 to 20 feet lower than the earlier, through the valley now occupied by the pond. These later waters carried little sand, and are represented, therefore, not by deposits, but by their erosive action. The faces of the terraces of the valleys were shaped in places by these waters, but in the main they are of the nature of ice-contact slopes.

CONCLUSIONS.

The results of the study of the Stoughton Bay area, in so far as they apply to retreatal conditions, prove: (1) that in this area the ice had become stagnant before the inception of the lakelets, and remained so throughout their history; (2) that the ice, previous to the emergence of the hills through its surface, was reduced almost entirely by superficial ablation; (3) that the subsequent melting was most rapid along the margins of the projecting land masses, because of the radiation of heat from them and the concentration of drainage along their borders; and (4) that the shrinkage continued to be outward in all directions from the exposed land masses, until the ice was reduced to narrow lines along the deeper valleys, and finally disappeared essentially simultaneously from all portions of the area.

APPLICATIONS.

Extent of glacial lakes.—Hitherto, in the discussion of glacial lakes in eastern Massachusetts, as was pointed out in the introduction, it has been assumed that the ice retreated with a rather definite and regular margin, in front of which extensive bodies of water accumulated in the northward-sloping valleys. While the observations of the writer have not been sufficiently extended to discuss in detail the conditions in other lakes, it has appeared almost certain from reconnaissance studies that the size of the open water bodies in the various lakes at any given time were much smaller than has usually been supposed, and that the marginal lakelets were very numerous, and definite and regular margins relatively rare, the ice having disappeared, in many instances, in the same manner as in the Stoughton area. Which type of retreat prevailed can be determined only by careful field work, though the facts now at hand seem to indicate that the mode of retreat discussed in the present paper is the most common.

Conditions in southeastern Massachusetts.—A study of the numerous, and often very large, kettle depressions in the stratified drift plains south of Middleboro, and at various other points in Plymouth county in southeastern Massachusetts, shows that throughout large areas in this part of the state extensive masses of stagnant ice existed during the final disappearance of the ice. How broad a belt of such ice existed at any one time or place cannot be readily determined, but in general the belt of no motion was probably not over ten or twenty miles in width, as more or less indefinite morainal bands indicating active ice-movements are found at intervals across the area, while occasionally more pronounced deposits occur.

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